NASA Administrator
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At 1:58 in the morning on December 4, a very important launch took place; this is 6 days ago. It was a cool, clear, stary night, but when we had ignition of that Delta rocket the sky glowed a golden color (with an "en" not an "in"). If you took a look as the rocket rose there was a jet black contrail against the night sky. We had to wait 90 minutes until we knew our spacecraft was on its way to Mars. It was sweaty palm time but we got there. And this flight marked a major signal that NASA is changing.

We have been struggling to change for the last few years but this was the definitive moment for us because we were turning to Mars to its surface not just to sit in one place but to have one of the most advanced robots in the world work its way over the surface of Mars. The exciting thing about this mission is that it didn't cost billions of dollars and take decades to perform but from the day we started it, until the day we launched it; it was three years. The rule I had set is no program should be longer than five years the time it takes to get a doctorate, so young people could work on it and not have to devote a whole career waiting for results. The spacecraft that got launched a few weeks before it, took 27 months from the time we started it until the day we launched it. Given that it will take a little less than a year to get to Mars there will be lots of time for science. And lots of time for PhD's. The other difference in this mission is in the past some of the people who got funded by NASA would have a one year hold on the data even though they got funded with public money, even though they had the knowledge that was intimate with those instruments and that no longer holds. The data will be made available immediately on the Internet to whoever wants it and we will let the scientific process determine who comes first with the analysis, not who had the funding or who is there first in line to receive it. So I view this mission as a declaration of independence for NASA that we're doing things differently.

Another exciting part about this mission is this was the first in a series of discovery satellites where NASA doesn't even specifiy the science. Every two years we throw the process open to competition to scientific and industrial teams to decide the science, to decide the implementation, and all we ask them to do is to fit within a specific cost window and not to exceed it. To live within a specific timeline and not to exceed it. Everything else is open. It's totally peer reviewed research and we have some incredible results coming out, and more and more this is the way we're going instead of the NASA scientists telling the scientific community and industry what the science is, then specifying every nut and bolt while saying you have academic freedom. We are doing it differently.

We stand today at the threshhold of unbelieveable discovery, not because it's happenstance, but because of the incredible work that has gone on for the prior five to ten years to get us to this point. Let me just list what happened this last year. We have found signs of fossilized life on a rock we found in Antarctica that we have been able to fingerprint as coming from Mars 16 million years ago, but the fossilized form of life being dated at about 3.6 billion years. A British team has found some samples of Mars rocks found at the South Pole with fossilized life that they believe is 600,000 years old. This is unbelievable. We recently think we found signs of frozen water in a crater on the South Pole of the Moon. The problem is this crater is higher in its peak than Mt. Everest, so you would have to climb over Mt. Everest and go down deeper to find what we think might be frozen water, but it might be an unbelievable resource for determining the pre-biotic condition because we believe the comet that landed there left the water there because there is no sunshine and the temperatures are on the order of hundreds of degrees below zero. In fact I think it's 300 degrees below zero. Think about what might be in there. Amino acids, building blocks of life; we don't know.

Then on Earth we have found what we believe are signs of life that are 3.85 billion years old. Think about that one. The Solar System, the protoplanetary disk formed we believe about 4 and one half billion years ago and as the planets in the solar system accreted through bombardment by planetesimals, comets, and asteroids, it was so hot due to the energy implanted that it was impossible for water to condense. But as the material got used up, the planets formed, Earth and Mars and Venus. Somewheres about 3.9 to 4 billion years ago, this constant violence and pounding subsided their occasional volcanic eruptions, but the fact of the matter is that the atmosphere started raining constantly and pools formed on the Earth. So within what we believe could be a fraction of a microsecond on a geological timescale from the conditions where life might form and transition from the prebiotic state to the biotic state we have found what we think is a sample. Also there has been some incredible research on looking for life under the surface; anaerobic life, life has been found in thermal vents under the ocean and sequenced and this life exists at 248 degrees Fahrenheit; think about that.

So you add these things up and then we say wow, we just had a spacecraft fly by Europa, a moon of Jupiter, and it had a resolution of one mile. This moon is bigger than our own Moon but smaller than Earth. It looks like almost a perfect sphere, but when you look at that sphere you see huge cracks in it and it looks like these cracks heal with time leading us to believe that we might be seeing a solid ice crust over a liquid water ocean. Why do we think this is possible? Because as these huge moons revolve about Jupiter, tidal action takes place and there is a friction that builds up in the core of these materials that supplies an energy source. Now if I have a frozen surface with an energy source at its core, we believe there could be the conditions for a liquid water ocean with an energy source and a transport mechanism, convection, and wherever we find those three conditions on Earth we find life.

In a few weeks the Galileo spacecraft is going to swing by so close that at a half billion miles out there we will have a resolution of 30 feet. We are going to take some more pictures and these pictures will be back sometime in January or February, and it may lead us to believe there could be a liquid water ocean on Europa.

We classically define the life zone as being that region away from the sun where the solar intensity is not so high that water would boil off the surface and not so far away that water would be permanently frozen. That was a very naive view. We now have a new view of what the life zone would be. The life zone is any place in the universe where we have liquid water, an energy source, and some transport mechanism. We also now in the last year have found eight planets around stars not our own. The human species has existed for hundreds of thousands of years and science has been incredible for the last three/four hundred but we had never found a planet around another star. We didn't know if our models of the formation of protoplanetary disks in the planets really played out. We are seeing some incredible anomalies. Now we might only detect large gas balls a few times larger than Jupiter, because they glow with their own energy; but if we want to find terrestrial size planets that are relatively close to the sun, in our own solar system we are one astronomical unit from our sun and about a 100,000,000 miles and the gas balls are anywhere between 5 and 40 astronomical units, so we have a problem. The energy coming from terrestrial size planets close to the sun is on the order of 1/10 billionth the energy coming from the star. So it is like picking a firefly out of a nuclear explosion. It is a little difficult to perform this nulling experiment and isolating out the background energy. But also we stand at the threshhold of unbelievable possibilities, which I will talk about later.

So our life zone has all of a sudden, in the last few years, expanded from Earth and Mars to a variety of places in our solar system. Now there is the possibility that there are life zones many places within a hundred light years of earth that's 600 trillion miles, there are some tens of thousands of stars; many like our own sun. We have only scratched the surface in finding these large gas balls now and we believe (which I will talk about later) within ten years we could directly detect earth size planets. So we really are on the threshhold of incredible things.

This is wonderful, but our Nation is facing a turning point. It's facing a turning point as we are transitioning out of a cold "Science and survival, technology and survival. I understand that." So they robustly funded the program starting with Vandevar Bush at the end of World War II. But now we are becoming a generation and a people that are a little too inward looking for the near-term gain in corporate America, and by the American people in our own government, and we are loosing the lock of the understanding in the criticality, of fundamental intellectual pursuit, in utilizing emerging technologies not to impact our lives but one generation downstream. This is the heart and sole of what I want to talk about today.

Now if we look at America before World War II we were second rate in science. The Europeans occasionally allowed us to talk to them, but we really didn't push it. Out of mere survival, a defining moment in science for America was World War II where we stepped up and we changed the whole course of that war with the injection of science and emerging technologies. And we did it on timescales that were unbelievable. Not decades where we compressed it into years. The outlay in human resource and dollars was enormous. And then World War II ended. The rest of the world was devastated. Asia and Europe had no infrastructure to speak of. So America faced a turning point at the end of World War II, and at that turning point our parents, at least my parents, your grandparents, faced this decision: Is America going to provide leadership in the second half of the century for the world by investing in long term research and intellectual pursuit, peer reviewed research, or are we going to coast and live off of what we did during World War II?

At that point in time the cold war was not on. It was a decision made by the American public that they believed in the future generations of this country and they said I'm responsible for America in the year 2000. I believe we must make this investment. And it was not just in the public sector, it was in the private sector. Bell Labs was thriving. And I'll come back to them in a minute. Corporate America was making an unbelievable investment in basic research understanding that in the process of training brilliant young people, in the process of expanding the minds of the researchers, they had the ultimate in tech transfer, the movement of people. The specific ownership of ideas was not as crucial as team America developing this capacity not to control the world but to lead the world and it ultimately helped us win the cold war.

Then the cold war ended and we are now in this period of change. And change is very, very difficult and we are trying to cope with it and understand it. But had we not made that decision as a Nation at the end of World War II, would there be a green revolution, would we be able to feed the number of people on this planet. I was born in 1940. There were a little over 2 billion people on this planet. Today there are close to 6 billion people. It tripled in my lifetime. Look how long it took to get to 2 billion people. But the green revolution happened because of that investment. The quality of health care, the electronics and information revolution; it wouldn't have been there. Where would we be today had we not done it? Now there are a variety of forces that are causing America to be uncertain. I would like to just spend a few minutes dealing with these forces because understanding the underpining forces of the change I think is important to see how we react to them.

First, the cold war is over, although many still want to fight it. Some people would like to keep on fighting the cold war and not prepare ourselves for what could be a war of 2020 which is a complete different activity and it involves a different set of investments. But to look at the contrast, a few weeks ago I had a videoconference with Yuri Koptev, the head of the Russian Space Agency. We talked about how we are going to work together in space using tens of thousands of engineers and scientists to build an international space station and then hopefully when we are done with that, explore Mars together. Doing it in cooperation, not in competition. To show a national macho which was necessary during the cold war. I think back to the conversations I had and the meetings I had just in the late '80's when I was involved in designing some of the most lethal weapons aimed against Yuri's home city. Yuri, who is exactly my age, did exactly the same thing in Russia. We cannot continue on a momemtum model saying we fought the Russians and therefore we must continue to fight the Russians and competition with Russia must drive us. We have to think about the possibility of changing the Russian attitudes. I don't want my grandson to go through air-raid drills and nuclear sneak attacks like I did. The best way to work with the Russians is to engage them, not to isolate them. Our whole financial system, our educational system, our foreign policy system, were set up to respond to the cold war. Now when we are having change, people are uncomfortable.

Second issue. Technological obsolence. The mean time to product obsolence used to be decades, and people could set up companies and make small evolutionary improvements to their products. Now you could be wiped out in a half year because someone has come to market with a revolutionary new design. Those revolutionary new designs will continue coming forward so long as America is commitedto the long ball. We are not going to feel the impact of cutting back on long-term basic research until maybe 10 years from now because we are living off backlog. Where is America going to be in the year 2020? As corporations worry about dealing with technological obsolence and fear the long-term research and want to milk what we have now to get these near-term products, I ask who is responsibe for

America in the year 2020? We are all Americans, and we all have to make some commitment to long-term basic research and emerging technologies that go with it, and not be in fear of making the quarterly, the daily, and yearly profit report. Or meeting the annual budget in America. You can do both.

Third issue. The global marketplace; we used to dominate the global marketplace and we bring the products forward and you would see American products all over. In the global marketplace; if you don't have the highest quality product and the lowest cycle time to market with the best performance, no one cares. You could go out and want to buy American all you want, I tried to buy an audio system built in America last year. The young man rolled on the floor when I asked for that. The fact that I couldn't get one; all the anger in the world about buying American is not going to change the fact that in audio equipment we don't have the highest quality at the lowest cost and the shortest cycle time to market. As we march away more and more from basic research without a program of applied research to match up with it what is going to happen in 20 years? That's another force that is causing displacement.

Fourth force, information and biological revolution. In 1984, 80% of a computer was manufactured on a production line like washing machines and TV sets. By 1990, 20% was manufactured. Today it is under 10% and the remainder is information intensive technologies. In the limit it will probably be 2% when we have a flat panel display and audio activated system with a voice chip. You know, one big super pentium processor, and that is all you got. You don't have a big box with a keyboard and all the other junk that goes with it. It's all information technologies. Yet our children are in school, uninspired, watching more TV than anywhere else in the world, becoming couch potatoes. They do not understanding the criticality of math and science to their futures because today 1 in 20 people earns their living in information intensive technologies and within two generations it's projected that one in two will be earning their living in information intensive technologies. So you can't drop out of school, go party, clear up at a trade tech and go back on a production line because there will be very few of those. So it says there must be an intellectual underpinning of what it is that we do.

And finally there is what I call the momemtum model strategy. We are going to maintain momemtum; we're different. The aircraft industry said we're different. We do wonderful things and we're going to sell jet planes. But the fact of the matter is in the last 25 years the dollars per passenger seat miles went up 50% and the revenues went down 50% for the airlines. How long do you think that industry is going to be in business? The CEO's are now saying we can't be different and we are going to have to address this issue. We have to cut the cost by a factor of three to five, perhaps, and not incremental three to five percent every five years. Or else there will be another means to overtake us. Corporations, universities, and the federal government must be cognizant of this momentum model saying everything is wonderful.

I got to NASA in 1992, and I was worried about the future of the Nation's space program and many people said "Dan, what are you worried about? The NASA budget doubled from 1983 to 1992, $7 to 14 Billion. Let the good times roll because we are going to double again to $30 billion by the end of the decade." I said no we are not. Listen to America. Wait for the election of 1992, the rest is history. So with regard to the space program, we had this momemtum model going. At NASA the average cost growth on a program was 77%. This was acceptable. Seventy-five percent of its work was non-performance based, non-peer reviewed. It cost billions of dollars and took decades to build spacecraft. We were a Space Agency and didn't design a new rocket in 25 years, but boy did we have loads of people hugging pieces of paper. Brilliant engineers, brilliant engineers, wonderful people at NASA because of the cold war methodology that bigger is better got wrapped up in this and we had an extra 10,000 people operating the Shuttle that we didn't need. The Shuttle was consuming the NASA budget and the Space station went for a decade and spent $10 billion. Let me repeat that for impact. $10 billion, not one piece of hardware was built, contractors made huge profits, and when I came in to review the program I said, "How are you awarding the contractors on award fee - we are only five years and billions of dollars behind, and we didn't build anything and there's no scientific underpinning." They said, "Boy we sent a message to them last month. We dropped the award fee from 95% to 93%." Good people - bad system.

So what we did was we set out to understand where NASA was going to go and we held Town Hall meetings around the country and the top management of NASA, it was mandatory that they went, because our customers, the American public, not the science community, not the contractors, would get our billions of dollars. The American community knows what it wants and we set a vision, and from that vision we have decided that what we are going to do is not build engineering temples in search of science, but we are going to ask fundamental scientific questions to define the technology and the emerging technologies that go with it. Let me review those seven questions for you because this is the basic underpinning of NASA. I'll let you fill in the blanks on which are biological in nature. I will not tell you.

Question 1 - How did the galaxies, stars, solar systems, planetary bodies and planetesimals form and evolve?

Question 2 - Is life of any form, single cell or higher, carbon based or not, unique to planet earth?

Question 3 - How can we develop an understanding of the biomass in the oceans, the atmosphere, and the land on our own planet by studying it and other planets to build predictive, environmental and climactic models better than 5 days? In 1996, the best model is 5 days and even that's not accurate. We want seasonal to interannual initially and then decadal models. Can we build those models so we understand the impact of the human species and nature on the environment that is precious to us?

Question 4 - How can we explore the space frontier with a very high level confidence of safety with human beings with ever increasing levels of productivity utilizing the marriage of those human beings with robotics and information intensive technologies? How do we protect their health when they are gone for years? How do we use the uniqueness of space, the unbelievable vacuum which you cannot replicate on the ground, the absence of gravity where you have no convection currents, buoyancy, or sedimentation, so you could literally rearrange things atom by atom to understand basic nature of inatimate and life objects?

Question 5 - How can we make air travel and space travel much safer than it is today? We are talking about a factor of 3 to 10 reduction in fatalities per flight. How can we make it more environmentally compatible and how can we make it economical to open up new markets for Americans and other countries?

Question 6 - How can we convert this knowledge, by inserting the technology in a proactive manner into the American economy, to impact the future economy for our children?

Question 7 - How do we communicate this knowledge directly without interpreters from the scientists to the American public in plain language that they can understand in a non-padantic form?

This is where the Space Station is going and this is the intellectual underpinnings of what we are trying to accomplish. I met with the leadership of this group during lunch so they said tell me the biological questions, and I said there are 3 1/2 biological questions in there and I leave it to you to pick them out.

We have four basic enterprises at NASA. One is Space

Science which studies, in essence, the first 2 1/2 questions. The evolution and formation of the universe and the search for life. The search for life I might say is not confined to other planets because before we can look for life on other planets we better understand it on our own, and we understand about 1% of the life forms on our own planet. So we have a new field of astrobiology which I will be talking about in a few moments which is emerging right here in the Bay Area. Dr. McDonald would you stand up. This is the Director of NASA, Ames Research Center, which is the Center of Excellence in the world for astrobiology when we figure out what it is and Harry will work with you on it.

The reason we are able to look at these new findings is that there are new tools. The sensitivity of the biological and physical tools and the resolution - we can look at things atom-by-atom - literally - and we can get unbelievable clarity and resolution with bacteria that could be 100 times smaller than those we have ever seen on Earth because of the tremendous progress made in this area. The progress we have made in robots - we are now talking about robots with tactile feel - these robots will be capable of operating completely autonomously. You see, when you go to Mars there is a 20 - 40 minute time delay at the speed of light for the signal to come from Earth to go to Mars and come back, so you cannot operate that robot. Then there are 2 - 4 weeks a year when the sun blocks Mars from Earth and you cannot communicate at all.

So this particular robot that we launched last week gets instructions to go from point A to Point B, and we are going into the entrance of ancient lake bed, we are landing July 4, that's by accident, 1997. We will program this robot and say go from Point A to Point B and it has a capacity to determine whether it can go over rocks or has to go around them. It has a capacity to understand the firmness, not of the Earth but of Mars. It has stereo-scopic imaging cameras; it has an alpha particle spectrometer so we can look at the actual composition and we can get microscopic like pictures with this 22 pound geologist that will be roving around the planet. It will cover an area equivalent to about a football field to start with, and the next generation robots will then be able to move miles and then tens and hundreds of miles.

We intend to have robots that fly in the Martian atmosphere, and take sounding measurements to search for water with electromagnetic techniques. Information systems are moving. And finally optics are really moving. The Hubble Space Telescope cost $2.5 billion to develop and it took well over a decade. It is 2.4 meters in diameter. We are now looking at technologies for new telescopes that we can put into space that are as large as 2 1/2 times the Hubble at 1/10th the weight, 1/10 the cost. We hope to have a demonstration of readiness within 2 to 4 years, and the development time of no more than 3 years after that to go launch this system. Having these kind of tools will allow us to peer out, when we combine this with a new form of optical system called interferometry, where you take a set of these telescopes - you send them out roughly to the orbit of Jupiter. We go out that far because when you take a look at inter-solar system measurements, look out at stars hundreds of light years - you have scattering. It's called zodiacal light. The remenants of the solar system are a lot of dust particles that are highest in density near the sun and as you go further out the density goes down so the extra zodiacal light is way down out by Jupiter - so you have a chance to look out. So we are going to send these very large telescopes that will be as much as 5 meters in diameter or more and some of them could be separated by tens of thousands of kilometers because we want to get incredible spatial resolution and with these devices we hope to be able to directly detect earth sized planets - remember that nulling problem I talked about.

If we are successful, in ten years we will start building instruments to directly detect earth size planets and perform remote sensing of their atmospheres to see what the constituent gases are if they exist. Then we will be able to have enough of a data base by ground truthing on Earth and other planetary bodies in our own solar system so when we make these remote measurements we will have more than a sample of one, or two, or three. As I said there are tens of thousands of suns like our own so the opportunity is enormous.

These technologies are monumental that could impact the whole future of the information industry that I talked about which is going to go up by a factor of 10 or more. It will impact the robotics industry, the semi-conductor industry, so it has a nice glow to it. They key to this is that NASA is fundamentally a physical science and enginering organization and we have very few people in the life sciences and biologists with us. So therefore, we are forming this new field called astrobiology which combines astronomy and biology to help us answer those questions I talked about. It's multi-disciplinary and I went to the American Physical Society before I came here (so you will know I'm being fair) I said when you train your young people, don't just train them in physics; give them some fundamental underpinnings in the biological sciences, so I say to you with no guilt as you train your young people, don't just train them in biology. Give them some fundamental skills and underpinnings in physics and chemistry - because the work is clearly multi-disciplinary, inter-disciplinary. We cannot have fields with soda straws where you purely talk to each other. It will have to be some combination of skills.

We have in the exiobiology/astrobiology field cosmic evolution of biogenic compounds. That's one field of study where you start literally with a big bang and work your way forward until you find carbon and hydrogen and phosphorous and oxygen and sulphur. Then we have pre-biotic evolution. When we talk about this we are not just talking about the issue of experimental work but we are talking about the theoretical underpinnings. One of the things NASA is very good at is high speed computations of very complex physical problems and developing the tools to do that and I think there is a tremendous potential marriage here between our skills and your theoretical bases. I didn't become a biological scientist or life scientist because I felt when I went to school it was an art. I was more interested in physics and engineering because it had closed form solutions. I think we will get very close to close form solutions here. There is some wonderful work going on at the Santa Fe Institute relative to the pre-biotic condition and trying to simulate a pre-biotic condition on a computer instead of in a test tube.

Then we need to look into the early evolution of life to determine the nature of the most primitive organisms and the environment in which they evolve. We have a whole series of spacecraft. It used to be that NASA would launch a few planetary spacecraft a decade. This year I think we are going to launch 5 planetary spacecraft. Our goal is, by the turn of the century, to be launching one a month. Many of them being build not in the big industrial plants and high-bay areas, but on the desktop in universities, by the students - no help. We want the students to do it. We want them to have the joy of discovery and also to experience failure, and not waiting for some big multi-billion dollar program - and they're post docs making $20,000 a year when they are 75 years old. Finally we have to look at the evolution of advanced life, and the factors influencing the development of advanced life, and its potential distribution not limited to just Earth and I'm not talking necessarily about intelligent life. But I would like to get just the multi-cellular life. So far we have a sample of one on multi-cellular life. That's our first enterprise. I think it has the most crossover appeal with your society and your training.

The second area is what we call Mission to Planet Earth. This is where we are trying to understand the interaction to bio-mass with the atmosphere, land, and oceans. We have studied the ecology of land and how biology impacts the chemical makeup of the oceans and atmosphere. Non-trivial problem. What are the sources and sinks of carbon dioxides? What is the carbon cycle? Very, very crucial to life on this planet. What we know about it would fit in the head of a thimble and we have loads more work to do to model this. Just as an example of a success for NASA, we studied the interaction of the chloroflourocarbons with the upper atmosphere at the South Pole by making measurements from space and flying converted U-2 aircraft to do in situ measurements. We are able to nail the photo chemical processes. We are able to clearly identify that the source of ozone depletion was chloroflourocarbons and I am proud to say that within 10 or 20 years the chloroflourocarbon content will be down and not building and you won't have to worry about skin cancer I hope.

Third area is Human Space Flight. This is to figure out how people can live and work safely with ever increasing productivity in space. At some point in the cycle we need human beings for their dexterity and their adaptability. The Hubble Space Telescope is a perfect example. We want to put upgrading and technology into the Hubble. There is no way we could have had robots do that mission in February 1993. The human interaction was unbelievable. When we do paleontology we don't send robots around the Australian Outback. We send geologists when it makes sense after you look at the land based photography and calculate the cost of sending people over. In a similar manner will send out precursor robotic missions, but ultimately we are going to send paleontologists and biologists and geologists to the surface of other planets. But, it would be irresponsible to send them without understanding how they live and work safely in space. This is one of the things we do on the Space Station. The other thing is microgravity research where we can eliminate convection currents, we eliminate bouyance, we eliminate other effects.

Finally, the last enterprise is Aero. Very little interaction for biology, but here we have a capacity for computational fluid dynamics and information systems. There are only two areas at NASA that are going to grow in the scientific area. Information Technology and Biological Technology. Because of the tremendous interaction between the biological and informational systems we have co-located these activities at NASA Ames. So Harry is the only Center Director who has the pleasure of actually hiring while everyone else in NASA is downstaffing. We are going to be building planes that travel at mach 2.4 without damaging the ozone layer; are quiet on take-off and landing, and will not have a premium on the coach ticket like the Concorde does - 10 times premium. We are doing a variety of other things.

So I think there are some very, very exciting things happening at NASA. It is an agency that is now safe for science again. Not because the people were bad, but because we had a system that focused on operations and engineering temples and now we want to start with the scientific underpinnings. We're doing it with fewer people, we started at 25,000, and by the time we are done at NASA we will have 17,500. We're at 20,500 right now. So we are moving, we want you involved. We are in the process of defining this astrobiology function. I talked to your leadership about how we could best engage you. Right now the program is funded shamefully low. We need your help to figure what is the appropriate level of ramping up the funding. What's the appropriate level for setting the scientific goals and bring people on board in an organized fashion? So again, here is an area where you have a capability and we have a need.

I leave you with this thought. There was a wonderful article in the Washington Post. It was about a researcher at Bell Labs. It appeared about two weeks ago. This fellow's name is Dr. Huang. He had been doing fundamental research in optical computing. He came there 10 years ago and it was very high risk, prone with loads of failure. As AT&T went from an institution, and they're not bad but they had the financial pressures of Wall Street. They focused away from basic research into applied research for near-term product development. Dr. Huang had to give it up. In the article he said you know, I worked on this and I taught the Japanese the fundamentals of it, and while I'm twiddling my thumbs the Japanese are investing $200 Million in optical computing. He went on to say, "Today, nobody wants to pay for research where the outcome is in doubt or the payoff is 25 years into the future. Even places like Bell Labs are not going to do Christopher Columbus stuff anymore. Now it's all Lewis and

Clark." At NASA this will never, ever happen again and we want to work with you. Thank you very much.

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LIFE IN THE UNIVERSE:
Evolutionary Biology and the Exploration of Space

Remarks Prepared for Delivery By:
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The dawn of the new Earth's day is barely perceptible. The faint young sun is not seen. It's shrouded by a thick and steamy smog.

The sea is bubbling. The few volcanoes that dot the horizon belch out fiery black smoke. The roof of this Hadean world is occasionally ripped by shooting stars streaking across the slate dawn.

Out of this chaos, at the first appearance of liquid water, life is born.

In that geologic instant, the incredible relation between physical, chemical and biological processes started on this water world.

Has it happened elsewhere? This questions has been asked for centuries. But only in this decade do we have the tools to begin to scientifically unravel our origins and the likelihood of life in the universe.

Lets start at:

THE BEGINNING OF THE BEGINNING

We know so much. Yet what we know about the creation and evolution of life and the universe could fit into a thimble.

I'm going to paint a picture for you that is based on our best guesses.

Let's go back 10 or 20 billion years, when out of the dark nothingness, the universe exploded. Let's go back to a time of force and fury. The the mysteries of the cosmos were unfolding.

Perhaps in the first few minutes, the first nuclei formed in the plasma of protons and electrons.

At 200,000 years from its beginning, the universe cooled to 4000K. Plasma combined into hydrogen and some helium. The universe is now transparent.

The universe cooled further. Gravity wells grew. Stars and galaxies formed in a universe of hydrogen and helium.

As the stars aged, they became fusion factories for producing heavier elements. A massive star exploded. It sent elements in all directions to become part of the interstellar medium.

Later, the elements condensed to form another star. The cyclical process of gravitational collapse and explosion continued. It produced the necessary elements for life - carbon, nitrogen, oxygen, phosphorous, and sulfur.

In the relatively cool outer atmospheres of red giant stars, a new family of chemical species was born. The first simple molecules of carbon and hydrogen, carbon and oxygen, carbon and sulfur were created.

Great interstellar clouds formed. A much wider range of compounds were created in the gas.

We have detected roughly 100 different chemical compounds in such clouds -- water, organic compounds like hydrogen cyanide, methane, and ammonia.

From such a cloud of gas and dust seeded with a complex family of molecules, our solar system began to form over 4.6 billion years ago. Earth and the planets formed. Comets and asteroids bombarded the proto-planets.

The planets were red hot, glowing with a boiling lava surface after every large impact. For over half a billion years, the planets were bombarded with rocks and metals. Life, if it occurred, could not be sustained.

Finally, after 600 million years ~ 3.9 billion years ago -- the noise and the fury faded. There was just an occasional splashdown of a leftover small planetoid.

Occasional comets, asteroids and other big chunks of matter brought molecular material, perhaps even amino acids and other building blocks of life.

The terrestrial planets cooled down. Rain fell continually as the steam in their warm atmospheres began to condense. This left behind thick atmospheres rich in carbon dioxide and nitrogen.

Venus, Earth, and Mars may have looked very much alike at this point. There were large bodies of water on planets. They were formed from water steaming out of volcanoes and from impacting comets. The oceans could sustain increasingly complex chemistries.

On the cusp of pre-biotic and biotic, there was a transition on Earth. But the record has been destroyed by recycling of the Earth's crust and by life itself.

For a prebiotic record, we must look elsewhere.

Pluto, comets and the Kuiper belt objects can give us an idea of the starting material that formed the planets. They can give us some hint of the organics that could have been delivered to a budding planetary body.

The organic world of Saturn's moon, Titan, has an orange atmosphere rich in reduced gases - methane, ammonia.

Saturn's satellite offers a 4-billion-year-old laboratory of organic reactions and photochemistry. This is chemical evolution on a planetary scale, perhaps analogous to the earliest prebiotic evolution on Earth.

THE BEGINNING OF LIFE

But how did life start on Earth?

Because we had water and energy, Earth went from pre-biotic (a chemical condition) to biotic -- with life.

Did Mars go through the same transition? We're beginning to think so. If so, does Mars still harbor life?

The oceans and atmosphere of Earth and perhaps Mars were alive with chemical reactions creating and consuming the chemicals of life. Some of the chemicals may have been self-replicating.

One of them might have been RNA. The planet was poised on the great divide between prebiotic and biotic development.

At the same time, Mars may also have been poised on the brink of the biotic transition. But did that happen?

At some point before 3 billion years ago, the paths of Earth and Mars diverged. Mars was too small a planet to trap the heat needed to move its huge crustal plates.

That slowed down the renewal of the atmosphere through volcanic action.

The Mars atmosphere began to thin. The planet became dryer and colder. Ice became the dominant form of water on the surface of Mars and below.

If life emerged on Mars at about the same time it emerged on Earth, it soon languished in shrinking pockets of warmth and liquid water.

This may be the end of the story for Mars. We'll have to go there to find out.

On Earth, somehow in this chaotic and violent period, life arose amazingly quickly -- 3.85 billion years ago.

We have preserved evidence of the earliest cells on Earth, over 3.5 billion years old. Are these "pictures" of our ancestors?

About 3 billion years ago, life began to split water and release oxygen through photosynthesis. The waste product, oxygen, gradually changed the atmosphere.

About 2 billion years ago, a new innovation appeared. One cell attempted to ingest another. A series of endosymbiotic relationships persisted. The result was more successful competitors.

Oxygen levels continued to rise.

The new oxygen atmosphere favored new species of cells. They consumed the waste oxygen and reduced it to carbon dioxide.

The oxygen-rich atmosphere shielded the surface from ultraviolet radiation. Life flourished, became increasingly diverse, and continued to evolve.

At some point, perhaps a billion years ago, cells began to act in groups.

Then, about 540 million years ago, there was an explosion of diversity. In a relatively brief period of time, all the major forms of life (phyla) developed.

Life continued to evolve to incredible levels of complexity. About 440 million years ago, plants began to colonize the land. Animals followed.

We know that large impactors changed the course of evolution. Sixty-five million years ago, a comet or asteroid struck the Earth, perhaps ending the age of the dinosaurs.

A chance event laid open the world for the expansion of mammals.

A few hundred thousand years ago, a full-blown Homo Sapiens arrived on the scene, with culture and technology. They are causing the current major extinction. This is the next random event in a long string of random events that have shaped our evolving, chaotic planet.

To understand the specifics of the changes here on Earth, we must understand the planetary development more generally. We must study other planets to fully understand how our own planet works and how life arises and evolves.

PERSPECTIVE

But, Earth is a sample of one for our information about life.

On Earth, all life forms are related. All Earth life is now known to be either a Bacteria, Eucarya, or Archaea. Fish, corn, people, sponges, bacteria we all have the same basic machinery (DNA, RNA, proteins). Earlier, life must have been much simpler. All that's needed for life are:

-Water (liquid)
-Energy (chemical or light)
-Available chemicals (as building blocks) and processes to transport and concentrate needed molecules.

Biological evolution is an offshoot of the evolution of the Universe.

One of NASA's functions is to increase the understanding of ourselves and our Universe. You are involved in doing that too, here on the ground, studying the biology of cells.

We at NASA are reaching out for the answers, but they are the same types of questions. We are looking for life in new places.

Now, we have to decide where we want to look. To do that, we have to decide on the life zone.

First, we are now working on the idea that life is a planetary phenomenon: a consequence of the evolution of a certain class of planets.

Since the only conclusive life we've found so far is on our sample of one, we will start with planets or planetary bodies.

-- These considerations define a life zone: a volume of space around certain stars in which the physical and chemical conditions conducive for life's origin and evolution could exist.

-- However, our current notions allow this life zone to be greater than it was once thought. We used to define the life zone as distance from a sun: where water would not boil away or be permanently frozen.

Now life zone is a volume of space that has water and where liquid water could exist. For example, using heat from tidal flexing to the planetary body itself.

The spectacularly active volcanoes on Jupiter's moon, Io, are good demonstration of this. The icy Jovian moon Europa has a fractured face that shows signs of being resurfaced, hinting of an ocean hidden deep beneath its crust.

If there's an ocean, heated by the constant push and pull of Jupiter, then there's the possibility of a hydrothermal system and of life. Imagine on another world a rich and varied ecosystem similar to the giant tube worms in our deep oceans, living on the bacterial oxidation of sulfur emanating from the crust.

The extension of the life zone may be more subtle. Last year's discovery of deep sub-surface bacteria on Earth means life can exist without any obvious reliance on the surface. Life can exist wherever there is liquid water -- such as life living in deep aquifers on Mars today.

STRATEGIES FOR LOOKING FOR LIFE

Here, we are guided by what we know about terrestrial life, but this is a single data point.

In the 1970s, two Viking spacecraft were dispatched to Mars. They monitored surface weather conditions, took pictures and tested the soil for signs of life. But that strategy to detect life could not distinguish biological chemical reactions from abiotic chemical reactions. No organics were measured, indicating no life on the surface.

Biological and technological advances made after Viking suggest that we would use strategies other than Viking's to look for life.

-We will be better prepared to choose sites of biological interest as a result of the current set of ongoing and planned Mars missions.

- We can expand our search space on the surface by going back in time, to a time when water flowed across the surface.

Looking for evidence of life, past or present, employs similar search strategies: One is, look for water or prior existence of water.

We would not confine our sampling to the surface but would look deep, under the surface.

The Viking technology for life detection was based on standard research tools, reduced in size, for studying a few specific aspects of biological chemistry.

I envision the new strategy to be based upon nanotechnological approaches working at the level of a few molecules or cellular units and capable of carrying out a large number of measurements - in essence a laboratory on a chip.

It doesn't need to be Mars. Other planets and their moons might contain environments conducive to life, e.g., Europa

We don't know yet where there has been life in our solar system. Eventually, we will send humans to Mars and possibly to other bodies in our solar system to continue to explore for signs of life.

Before we send humans, certain criteria will have to be met.

When we do research on Earth, paleontologists don't just rush off on an expedition.

They lay the groundwork. They send planes to fly over the area. They study maps. They do their homework.

We don't want a feel-good mission to Mars. We need to do our homework and know what we're doing.

These missions need to be driven by scientific necessity and the economic desires of the country.

We have a rich robotic program on the books. We have dozens of early recognizance missions planned.

But ultimately, we'll have to send humans. They're adaptive. They have dexterous capabilities. They can think on the spot.

There is simply no substitute for the eyes and ears and brain of a human being.

But we need to do this cheaply and we need to work with other countries to do it. The quest for knowledge and inspiration has no national boundaries. It's everyone's goal, everyone's dream.

HOW TO TELL IF LIFE EXISTS IN OTHER SOLAR SYSTEMS

When looking out at other star systems, how could we tell if life exists? What are the potential atmospheric signatures for life?

For the last two billion years, Earth's atmosphere has had a distinctive ozone signature -- a sure indicator of oxygenic photosynthesis.

Methane or nitrous oxide in the presence of oxygen could be clues.

But in a primitive atmosphere, before oxygenic photosynthesis, organic sulfur rich compounds could be indicative of life in a reducing atmosphere.

A predominance of an optically active pigment, like chlorophyll or rhodopsin, could be indicators.

We'll look for a planet with water as a start. We'll limit it on purpose to look for water partly to have a focus.

We need a vision of what life on another planet might be like and the kind of things that we might develop to explore it.

Perhaps we'll find a blue/purple Earth-sized planet.

Maybe we will find a world that doesn't use photosynthesis but is dependent on other chemical fluxes like hydrogen emanating from a planet's deep in interior.

NEW TOOLS

It is only in this century that we have the tools, in biology and in space exploration, to credibly hope to answer the questions: What are our origins? Are we alone?

In the laboratory, great gains in sensitivity and resolution have been accomplished. Evidence for Earth's earliest life was discovered using an ion probe and mass spectrometer capable of measuring carbon isotopes of 20 picograms.

A dual laser mass spectrometer was used to detect the polycyclic aromatic hydrocarbons found in the ancient Mars meteorite, ALH84001, and high-resolution SEM has shown us the purported microfossils.

Other gains in discovering Earth's history come with dating techniques. The accuracy of potassium/Argon dating combined with Argon 39/Argon40 to account for potential Argon loss has put 1-million-year resolution on billion-year dating.

Ancillary techniques of matching rock layers by patterns of paleomagnetic, oxygen isotopic or strontium 87/86 variations can achieve 10,000-year resolution.

We can already achieve single molecule detection in some techniques, now is the time to push to develop efficient delivery methods to the detector so that the ultimate limiter is the statistics of the number of atoms or molecules.

Amazing strides have been made in biology. We can now start looking at the ultrastructure of cells in their environment. We have the microtechniques to follow cell function.

On molecular biology, we can now sequence whole genomes. This recently confirmed the three kingdom world and how much we don't know about life on our own world.

These techniques aid us in determining life's story on Earth but, we are limited - by the paucity of rocks from early Earth and the incomplete phylogenetic record that can only relate to us our last common ancestor. We must look elsewhere.

NASA MISSIONS

NASA has spacecraft already operating and some in the planning stages that can look for life or conditions that could presuppose life.

Hubble: The Hubble Space Telescope has changed the way we look at our solar system and our universe.

Hubble has imaged the very early stages of star formation showing disks of dust and gas that most likely will condense into planets - implying that planet formation might be universal.

NEAR: In February of this year, we launched the Near Earth Asteroid Rendezvous mission or NEAR.

NEAR's mission is to orbit around the asteroid Eros studying it, giving us vital information about a type of body we know little about.

Stardust: A future spacecraft is Stardust. Stardust will be unlike anything we've ever done before. It is designed to gather samples of dust spewed from a comet and return the dust to Earth for detailed analysis. This could tell us of the solar system's earliest chemistry.

NEAR and STARDUST are discovery missions. A new way of doing space exploration in which a principal investigator proposes a cost-capped mission.

We have two spacecraft racing to Mars right now and we are sending 10 missions to Mars over the next 11 years. These missions, including robotic and sample return missions, will lay the groundwork for piloted missions of exploration. These missions will be driven, in part, by evolutionary biology.

Infra-red interferometry with long baselines on the ground will soon enable the detection of large planets at distances more similar in location to the gas giants in our solar system.

State-of-the-art interferometry will be developed and used in space to seek and find Earth-like planets around other stars if they exist.

We also want to use it to do analyses of atmospheres to look for signs of life. Ultimately, we want to take pictures, if technically feasible, with a resolution that shows us oceans and continents.

A hundred meters long and orbiting out beyond Jupiter, the planet finder should be able to null the blinding light of neighboring stars and spot the faint glow of a potential home for life.

Origins: Its purpose is threefold:

- to understand how stars, galaxies, other solar systems and planetary bodies formed and evolved.

- to search for other Earth-like planets and analyze their atmospheres for life-sustaining elements.

- to search for life of any form -- single-cell or higher, carbon-based or not.

Origins is taking off now because of the incredible things that have happened this last year:

- 3.6B fossil on Mars
- potential liquid water on Europa
- frozen water on the Moon
- fossilized life on Earth as early in the process as possible
- fossilized life in deep ocean vents
- planets around stars other than our own

These discoveries didn't happen by accident. They resulted from major technical breakthroughs. New biological and physical tools made this possible.

NASA and other critical funding agencies like NSF and the Keck Foundation, have been investing heavily in these technologies.

Over the next two decade, we anticipate breathtaking possibilities.

GETTING GROUND TRUTH

How does investigating the life zone of this solar system relate to our search for other solar systems?

It's our ground truth. We'll apply what we learn about the life zone in our solar system to our studies of worlds around other stars.

We've already found eight Jupiter-sized bodies orbiting distant stars.

We hope to detect more and smaller bodies like Earth or moons of those Jupiter-size planets, maybe even moons like Europa and Titan.

Only through understanding the conditions under which life can or did develop here, can we guess whether these new bodies are hospitable to life forms.

There may be life forms we don't understand, so we'll have to really be open and scientifically imaginative.

One question is not whether there are planets around other stars, but whether there are Earth-like planets (little blue/green dots) orbiting other stars or other planets, different from Earth, but capable of supporting life as we know it.

WHAT WILL GUIDE OUR SEARCH

To pursue this vision we will need to develop a research plan: a roadmap which will outline the objectives that need to be accomplished and the steps that will be taken.

While the details of this plan remain to be developed, there are a number of principles that will guide us:

- Biology and information systems will be among the driving forces for science and technology in the next 25 years. NASA's research programs will recognize and not only be responsive to these forces but will lead the way.

-NASA will be driven by science that is centered around Evolutionary Biology; those processes by which life expands its presence in either time or space, or both.

We will develop and implement our research programs by engaging other agencies and nations to leverage on their expertise and capabilities.

We will work with the NSF, the NIH , the Academy, and professional societies, such as yours.

For the first time in history, we are about to leave Earth to explore.

We've been talking about biological transitions.

Now we are the critical transition of life leaving Earth.

The evidence of these transitions are all restrospective -- fossil records, embryology and biochemical patterns. Now we may have the opportunity to study life on other planets.

I hope that my talk has stimulated within you both the excitement and scientific challenge inherent in this vision, and you are already imagining ways in which your knowledge and expertise as Cell Biologists can contribute.

We will solicit research through formal announcements such as NASA Research Announcements, and select proposals through strict peer review.

I am fully committed to supporting the implementation of this vision and I will find the necessary resources to make it happen.

NASA's research must be multidisciplinary. We must bring together cell and evolutionary biologists, geneticists, paleontologists, geologists, physicists, chemists, engineers, and information scientists.

This multidisciplinary approach suggest that a new discipline may evolve out of this research program: the discipline of Astrobiology.

What is Astrobiology? It is defined in the NASA strategic plan as the multidisciplinary study of life in the universe, including (1) origin, evolution and distribution of life, (2) adaptation of life to space, and (3) studies of life on Earth from space.

- We will provide new vistas and dreams for young people. We will look out as far as the aided eye can see and as far as the translated hand can touch and explore the laws of nature to understand our origins and enrich the lives of our children.

- We will develop new technologies based upon biological processes and systems:

- A "chemical nose" to detect hundreds of volatile organic substances
- Accelerometers based upon the inner ear
- DNA-based biomedical diagnostic sensors
- Self diagnosing and repairing mechanical systems
- Biological production of non-biological materials
- Micromachine explorers equipped with tri-corder capability

We have more questions than answers. I suspect as inquisitive human beings we always will. But now more than ever, you and I stand on the edge of an exciting new adventure.

We are looking at the stars. They may hold the answer to our questions about who we are and where we came from.

Today, I have asked you to broaden that question. Not only to ask how we developed on this Earth, but if we have cousins created out of the same star stuff on distant planets.

Let's jump ahead just a little bit for the moment -- maybe ten years.

You are sitting in your den, watching t.v. Suddenly, your program is interrupted. A newscaster appears on the screen to bring you a NASA press conference live.

Amorphous shapes emerge on your screen, beamed in directly from space.

You see black clouds and refractive swirls. Off to one side you see a patch of color, which begins to grow.

You hold your breath, and strain to see. The images are still indistinguishable, occasionally blocked by smoke or blurred by turbulence.

Suddenly, the picture clears. Amidst and around the boiling black towers are strings of mucousy material waving in the water. Multi-tentacled forms dance in the eddies. You and the world have just seen life on Europa.

It's a great future.

Thank you.

LIFE IN THE UNIVERSE:
Evolutionary Biology and the Exploration of Space

Remarks Prepared for Delivery By:
Daniel S. Goldin
Administrator
National Aeronautics and Space Administration

The International Congress on Cell Biology and the American Society for Cell Biology
Annual Meeting
December 10, 1996
San Francisco

I've just discovered that someone, somewhere, discovered how to travel in time and went all the way back to the beginning of the universe.

We don't know who this person is. We don't know how they managed it. All we have is their log. The pages are yellow and crumbling. But the words are still legible.

I'd like to start today by reading a section of the log to you:

"The dawn of the new Earth's day is barely perceptible. The faint young sun is not seen. It's shrouded by a thick and steamy smog..

The sea is bubbling. The few volcanoes that dot the horizon belch out fiery black smoke.

The roof of this Hadean world is occasionally ripped by shooting stars that streak across a slate dawn.

It is chaos. It is awful. It is beautiful.

Liquid water appears. Something momentous is about to happen. There is a breath, a whisper of it in the air around me. It is the birth of life."

Here we have a description of the beginning of life.

Has it happened elsewhere? People have asked this question for centuries. But this decade, we have the tools to begin to unravel our origins and the likelihood of life in the universe.

Let's start at:

<u>THE BEGINNING OF THE BEGINNING</u>

We know so much. Yet what we know about the creation and evolution of life and the universe could fit into a thimble.

I'm going to paint a picture for you that is based on our best guesses.

Let's go back 10 or 20 billion years, when out of the dark nothingness, the universe exploded. Let's go back to a time of force and fury. The mysteries of the cosmos were unfolding.

Perhaps in the first few minutes, the first nuclei formed in the plasma of protons and electrons.

At 200,000 years from its beginning, the universe cooled to 4000K. Plasma combined into hydrogen and some helium. The universe became transparent.

The universe cooled further. Gravity wells grew. Stars and galaxies formed in a universe of hydrogen and helium.

As the stars aged, they became fusion factories for producing heavier elements. A massive star exploded. It sent elements in all directions to become part of the interstellar medium.

Later, the elements condensed to form another star. The cyclical process of gravitational collapse and explosion continued. It produced the necessary elements for life - carbon, nitrogen, oxygen, phosphorous, and sulfur.

In the relatively cool outer atmospheres of red giant stars, a new family of chemical species was born. The first simple molecules of carbon and hydrogen, carbon and oxygen, carbon and sulfur, were created.

Great interstellar clouds formed. A much wider range of compounds were created in the gas.

We have detected roughly 100 different chemical compounds in such clouds -- water, organic compounds like hydrogen cyanide, methane, and ammonia.

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Amazing strides have been made in biology. We can now start looking at the ultrastructure of cells in their environment. We have the microtechniques to follow cell function.

On molecular biology, we can now sequence whole genomes. This recently confirmed the three kingdom world and how much we don't know about life on our own world.

These techniques aid us in determining life's story on Earth but, we are limited - by the paucity of rocks from early Earth and the incomplete phylogenetic record that can only relate to us our last common ancestor. We must look elsewhere.

NASA MISSIONS

NASA has spacecraft already operating and some in the planning stages that can look for life or conditions that could presuppose life.

Hubble: The Hubble Space Telescope has changed the way we look at our solar system and our universe.

Hubble has imaged the very early stages of star formation showing disks of dust and gas that most likely will condense into planets - implying that planet formation might be universal.

NEAR: In February of this year, we launched the Near Earth Asteroid Rendezvous mission or NEAR.

NEAR's mission is to orbit around the asteroid Eros studying it, giving us vital information about a type of body we know little about.

Stardust: A future spacecraft is Stardust. Stardust will be unlike anything we've ever done before. It is designed to gather samples of dust spewed from a comet and return the dust to Earth for detailed analysis. This could tell us of the solar system's earliest chemistry.

NEAR and STARDUST are discovery missions. A new way of doing space exploration in which a principal investigator proposes a cost-capped mission.

We have two spacecraft racing to Mars right now and we are sending 10 missions to Mars over the next 11 years. These missions, including robotic and sample return missions, will lay the groundwork for piloted missions of exploration. These missions will be driven, in part, by evolutionary biology.

Infra-red interferometry with long baselines on the ground will soon enable the detection of large planets at distances more similar in location to the gas giants in our solar system.

State-of-the-art interferometry will be developed and used in space to seek and find Earth-like planets around other stars if they exist.

We also want to use it to do analyses of atmospheres to look for signs of life. Ultimately, we want to take pictures, if technically feasible, with a resolution that shows us oceans and continents.

A hundred meters long and orbiting out beyond Jupiter, the planet finder should be able to null the blinding light of neighboring stars and spot the faint glow of a potential home for life.

Origins: Its purpose is threefold:

• to understand how stars, galaxies, other solar systems and planetary bodies formed and evolved.

• to search for other Earth-like planets and analyze their atmospheres for life-sustaining elements.

• to search for life of any form -- single-cell or higher, carbon-based or not.

Origins is taking off now because of the incredible things that have happened this last year:

- 3.6B fossil on Mars
- potential liquid water on Europa
- frozen water on the Moon
- fossilized life on Earth as early in the process as possible
- fossilized life in deep ocean vents
- planets around stars other than our own

These discoveries didn't happen by accident. They resulted from major technical breakthroughs. New biological and physical tools made this possible.

NASA and other critical funding agencies like NSF and the Keck Foundation, have been investing heavily in these technologies.

Over the next two decade, we anticipate breathtaking possibilities.

GETTING GROUND TRUTH

How does investigating the life zone of this solar system relate to our search for other solar systems?

It's our ground truth. We'll apply what we learn about the life zone in our solar system to our studies of worlds around other stars.

We've already found eight Jupiter-sized bodies orbiting distant stars.

We hope to detect more and smaller bodies like Earth or moons of those Jupiter-size planets, maybe even moons like Europa and Titan.

Only through understanding the conditions under which life can or did develop here, can we guess whether these new bodies are hospitable to life forms.

There may be life forms we don't understand, so we'll have to really be open and scientifically imaginative.

One question is not whether there are planets around other stars, but whether there are Earth-like planets (little blue/green dots) orbiting other stars or other planets, different from Earth, but capable of supporting life as we know it.

WHAT WILL GUIDE OUR SEARCH

To pursue this vision we will need to develop a research plan: a roadmap which will outline the objectives that need to be accomplished and the steps that will be taken.

While the details of this plan remain to be developed, there are a number of principles that will guide us:

- Biology and information systems will be among the driving forces for science and technology in the next 25 years. NASA's research programs will recognize and not only be responsive to these forces but will lead the way.

-NASA will be driven by science that is centered around Evolutionary Biology; those processes by which life expands its presence in either time or space, or both.

We will develop and implement our research programs by engaging other agencies and nations to leverage on their expertise and capabilities.

We will work with the NSF, the NIH , the Academy, and professional societies, such as yours.

For the first time in history, we are about to leave Earth to explore.

We've been talking about biological transitions.

Now we are the critical transition of life leaving Earth.

The evidence of these transitions are all restrospective -- fossil records, embryology and biochemical patterns. Now we may have the opportunity to study life on other planets.

I hope that my talk has stimulated within you both the excitement and scientific challenge inherent in this vision, and you are already imagining ways in which your knowledge and expertise as Cell Biologists can contribute.

We will solicit research through formal announcements such as NASA Research

Announcements, and select proposals through strict peer review.

I am fully committed to supporting the implementation of this vision and I will find the necessary resources to make it happen.

NASA's research must be multidisciplinary. We must bring together cell and evolutionary biologists, geneticists, paleontologists, geologists, physicists, chemists, engineers, and information scientists.

This multidisciplinary approach suggest that a new discipline may evolve out of this research program: the discipline of Astrobiology.

What is Astrobiology? It is defined in the NASA strategic plan as the multidisciplinary study of life in the universe, including (1) origin, evolution and distribution of life, (2) adaptation of life to space, and (3) studies of life on Earth from space.

- We will provide new vistas and dreams for young people. We will look out as far as the aided eye can see and as far as the translated hand can touch and explore the laws of nature to understand our origins and enrich the lives of our children.

- We will develop new technologies based upon biological processes and systems:

- A "chemical nose" to detect hundreds of volatile organic substances
- Accelerometers based upon the inner ear
- DNA-based biomedical diagnostic sensors
- Self diagnosing and repairing mechanical systems
- Biological production of non-biological materials
- Micromachine explorers equipped with tri-corder capability

We have more questions than answers. I suspect as inquisitive human beings we always will. But now more than ever, you and I stand on the edge of an exciting new adventure.

We are looking at the stars. They may hold the answer to our questions about who we are and where we came from.

Today, I have asked you to broaden that question. Not only to ask how we developed on this Earth, but if we have cousins created out of the same star stuff on distant planets.

Let's jump ahead just a little bit for the moment -- maybe ten years.

You are sitting in your den, watching t.v. Suddenly, your program is interrupted. A newscaster appears on the screen to bring you a NASA press conference live.

Amorphous shapes emerge on your screen, beamed in directly from space.

You see black clouds and refractive swirls. Off to one side you see a patch of color, which begins to grow.

You hold your breath, and strain to see. The images are still indistinguishable, occasionally blocked by smoke or blurred by turbulence.

Suddenly, the picture clears. Amidst and around the boiling black towers are strings of mucousy material waving in the water. Multi-tentacled forms dance in the eddies. You and the world have just seen life on Europa.

It's a great future.

Thank you.

DRAFT

LIFE IN THE UNIVERSE:
Evolutionary Biology and the Exploration of Space

A Speech by the Administrator to:

The American Society for Cell Biology
International Meeting

December 7-11, 1996
San Francisco

1. The Origin of Life

- To understand the processes that might have given rise to life on Earth, one needs to define life to determine what specific questions to ask or processes to look for.

- This has occupied biologists for decades but I would suggest that a functional definition would include the following:

  - capable of self replication
  - capable of undergoing heritable changes
  - containing a selective barrier to the environment

- With this in mind let me review for you our current hypotheses on the origin of terrestrial life:

Let's go back 10 or 20 billion years ago, when out of the dark nothingness, the universe exploded. Let's go back to a time of force and fury, when the mysteries of the cosmos were unfolding. In the first few minutes the elements form in the plasma of protons and electrons. At 200,000 years from the beginning the cools to 4000K and the plasma condenses into hydrogen and some helium and is now transparent. COBE pictured this residual radiation, showing signs of inhomogeneity on a grand scale.

The Universe cools further, Does hydrogen become molecular? Gravitational potential wells grow, stars and galaxies form.

As the stars age, some of them become factories, first for producing the heavy elements, producing the necessary elements for life - carbon, nitrogen, oxygen, phosporous, and sulfur.

In the relatively cool outer atmospheres of red giant stars a new family of chemical species is born. The first simple molecules of carbon and hydrogen, carbon and Oxygen, Carbon and Sulfur are created.

Exploding stars seed the universe with the heavy elements. Great interstellar clouds form. At very low temperatures and under the influence of ionizing radiation, a much wider range of compounds are created in the gas. Some reactions are catalyzed by small metal grains that provide a surface on which reactions take place.

We have detected roughly 100 different chemical compounds in such clouds -- water, Organic compounds like Hydrogen Cyanide, Methane, Ammonia, Methanol, acetylene, and many inorganic molecules including Sulfur dioxide and sodium hydroxide and Silicon sulphied.

From such a cloud of gas and dust seeded with a complex family of molecules, our solar system began to form over 4.6 billion years ago. What were the chemical and physical interactions that followed? How is the complex chemistry of an interstellar dust cloud affected by the process of collapse and the ignition of a star?

How did an Earth so rich in chemical complexity come to be?

About 4.6 billion years ago -- the protoplanetary disk forms. A more complex chemical environment was developing. Earth was forming, Mars was forming. Comets and asteroids bombarded the proto-planets.

Mars and Earth are red hot, glowing with a boiling lava surface. For over half a billion years, they're bombarded with rocks and metals. There is no life. No living things could withstand the heat and the pounding they're taking.

Finally, after 600 million years 3.9 billion years ago the bombardment subsides. The noise and the fury fade. There's just an occasional splashdown of one of the leftover small planetoids. Comets, asteroids and other pre-planetary chunks of matter bring molecular material, perhaps even amino acids and the building blocks of life.

Both the Earth and Mars have cooled down. Their temperatures are below the boiling point of water. Polar caps are beginning to form. Rain falls continually as the steam in their warm atmospheres begins to condense. This leaves behind thick atmospheres rich in carbon dioxide and nitrogen.

The Earth and Mars look very much alike. There are large bodies of water on both planets, formed from water steaming out of volcanoes and from impacting comets. The oceans of Mars and Earth both sustain increasingly complex chemistries.

Think in terms of pre-biotic, and biotic.
Because we had water and energy, Earth went from pre-biotic (a chemical condition) to biotic --- with life. Did Mars go through the same transition? If so, does Mars still harbor life?

The Oceans and atmosphere of Earth and perhaps Mars were alive with chemical reactions creating and consuming the chemicals of life. Some of the chemicals may have been self replicating. One of them might have been RNA.

A process of chemical evolution wrote and re-wrote the recipe for the vast prebiotic soup that covered a significant part of the Earth. The planet was poised on the great divide between prebiotic and biotic development.

At the same time, Mars may also have been poised on the brink of the biotic transition.

What role did the continuing series of impacts play? How important were atmospheric disturbances and lightning? What role did plate tectonics, volcanism, even the creation of clays and silts play?

Life occurred amazingly quickly on Earth - 3.85 billion years ago, we have evidence of life. The rain of impactors was near its end. Somehow, from the right set of ingredients, in this chaotic and violent period, life arose. By 3.5 billion years ago, we have ppreserved evidence of the first cells. The first cells emerge over 3.5 billion years ago.

At some point before 3 billion years ago, the paths of Earth and Mars diverge. Mars is too small a planet to trap the heat needed to move its huge crustal plates. That slows down the renewal of the atmosphere through volcanic action.

So the Mars atmosphere begins to thin. The planet becomes dryer and colder. Ice is now the dominant form of water on the surface of Mars and below. If life emerged on Mars at about the same time it emerged on Earth, it soon languished in shrinking pockets of warmth and liquid water. This may be the end of the story for Mars. There may be more clues, fossilized life, or even living organisms on Mars. We will have to go there to find out.

On Earth, early cells develop which derive sustenance from early solar system materials such as carbon dioxide, and ammonia; or from geothermal activity or peptides that still floated in the newly biotic ocean.

The cell membrane uses energy from chemical reactions to control the internal environment of the cell. The cell uses metabolic energy to regulate the concentrations of key substances. Protoplasm, a new kind of biotic soup is born.

Within the new environment of the cell, an even more complex chemistry continues to evolve as cells compete for resources in Earth's newly biotic oceans.

About 3 billion years ago Life begins to split water and release oxygen through photosynthesis. Bacteria use solar energy and carbon dioxide to make the stuff of life.

Photosynthetic life produces a waste product, Oxygen that gradually changes the atmosphere. First the Earth absorbs the excess oxygen as elements like iron and sulfur bond with newly available oxygen.

Volcanic gasses also react with oxygen and remove it from the atmosphere. Overtime, fewer volcanoes erupt, and volcanic gasses account for less of the oxygen.

Decaying plants and animals also consume oxygen. But when geological processes bury the remains of animals and plants, an oxygen surplus results.

Oxygen is highly reactive. For much of the life of the time, increasing concentrations of oxygen are toxic. Eventually the cells which could not tolerate oxygen (anaerobes) are forced underground and into other environments where there is no oxygen._

About 2.3 billion years ago, the use of oxygen for energy, (aerobic respiration) becomes wide spread. __

About 2 billion years ago a new innovation appears. One cell attempts to ingest another. But rather than leading to the death of either cell, a symbiotic relationship persists and the result is a more successful competitor that creates more progeny. The "ingested cells become discrete specialized units enclosed in a separate membrane floating within the cell that attempted to ingest them. These specialized "cells within a cell" (called organelles) represent a major advance. Some of the ingested cells become specialized chlorophyll machinery for using solar energy (chloroplasts), others become machinery for improved Oxygen respiration (mitochondria).

The ancestral cell to plants and animals had existed almost from the beginning of the cell. Now, with the new organelles this line of cells have acquired a major advantage.

Oxygen levels continue to rise.

The new oxygen atmosphere favors new species of cells that consume the waste oxygen and reduce it to Carbon dioxide.

The oxygen-rich atmosphere shields the surface from ultraviolet radiation. Life flourishes, becoming increasingly diverse and continues to evolve.

A complex set of competitive and cooperative chemical, physical and biological interactions have created a thriving biosphere of single-celled organisms.

At some point, perhaps a billion years ago, cells begin to act in groups.

Then, about 540 million years ago, an explosion of diversity. In a relatively brief period of time, all the major forms of life (phyla - *fie* *la*) have developed. But plants and animals have probably not yet left the water.

600 million years ago multicellular animal life is clearly evident.

Life continues to evolve to incredible levels of complexity in constant interaction with the development of the planet. About 440 million years ago plants begin to colonize the land, animals follow.

About 230 million years ago, a major extinction event. The Permian/Triassic extinction takes a major toll. Changing positions of the continents limit mixing in the ocean. This might have caused a build-up of carbon dioxide leading to a catastrophic outgassing from the cold oxygenless depths. The sudden increase in carbon dioxide concentrations might have suffocated life in shallow water. (Lake Nyos effect)

65 million years ago the animals that live on land include both mammals and dinosaurs. Then, a comet or asteroid strikes the Earth perhaps ending the age of the dinosaurs. The impact leaves behind a huge crater in Mexico. A chance event lays open the world for the expansion of the mammals.

Then, perhaps one or two million years ago a peculiar genus of mammals walks out of central Africa. The world is exposed to Homo erectus. A few hundred-thousand years ago a full-blown Homo Sapiens infection breaks out. Its the next great extinction event, the next random chance in a long string of random events that have shaped our evolving, chaotic planet.

We must understand the planetary development more generally in order to understand the specifics of the changes here on Earth. We know that events on Earth are tied to impacting bodies from space throughout Earth history. But more than this, we must study other planets to fully understand how our own planet works and how life arises and evolves.

- Planetary bodies of the Solar System provide signposts along the road of biotic history. (refer to "hourglass" figure for strategy of searching for evidence of life in the solar system).

Pluto, the Kuiper Belt, and comtes preserve the early solar system volatiles and organic molecules.

The organic world of Saturn's moon, Titan, offers a 4 billion year old reaction vessel within which to explore organic reactions, chemical evolution on a planetary scale, perhaps analogous to the earliest prebiotic evolution on Earth. Possible episodes of liquid water may have enabled initial proto-biological chemistry and subsequent low temperatures, frozen the the chemical events in a stratigraphic record. Even Europa, an icy moon of Jupiter, heated buy the constant push and pul of Jupiter, could have an ocean and perhaps hydrothermal ecosystem in an ocean beneath its thick frozen surface.

- Key Points

-. Life is a planetary phenomenon: a consequence of the evolution of a certain class of planets

-Conditions necessary for life to initiate include:

-Water (liquid)

-Energy (chemical or light)

-Available chemicals (as building blocks)

- life seems to have originated on Earth in a startlingly short time (present estimates; within the first 700 million years of Earth's 4.5 billion years of existence)

-- These considerations define a life zone: a volume of space around certain stars in which the physical and chemical conditions conducive for life's origin and evolution could exist.

- However, our current notions allow this life zone to be greater than it was once thought. We used to define the life zone as distance from a sun: where water would not boil away or be permanently frozen Now life zone is a volume of space that has water and where liquid water could exist For example using heat not from the sun, but from tidal flexing ot the planetary body itself (Europa).

2. Life on Earth and the Solar System

If we were to explore the universe for life, how would we recognize life if it were found? Here, we are guided by what we know about terrestrial life. We recognize that this is a single data point and, possible, a significant limitation. To reduce the impact of this limitation we envision experiments based upon emulating the alien planetary environment, e.g., Mars, as best we can (we can't reduce the earth's gravity) in research laboratories, and exposing a wide variety of the appropriate micro-organisms to these environments. We hope, by these experiments in accelerated evolution, to cause the selection of organisms better "fit" to these alien environments and thereby gain clues as to what might be the characteristics of micro-organisms native to that planet.

-Viking: The Viking strategy for identifying the presence of life on Mars was based upon looking on the surface for chemical reactions typical of terrestrial microbes. Why microbes? Micro-organisms appeared very early on Earth, are ubiquitous and their metabolism is critical to the stability of the global ecosystem. Their biomass may make up upwards of 90% of the terrestrial biomass. However, it has been estimated that no more than 0.1% of current microbial species have been identified. The vast majority of these forms remain to be described and, more importantly, their roles in maintaining the ecosystem understood. This is the biological equivalent of the cosmic dark matter which has so challenged the astrophysicists.

- The Initial Viking results were very exciting as they appeared to indicated the presence of life. However, the Viking life detection strategy could not distinguish biological chemical reactions from abiotic chemical reaction, which the Viking results proved to be.

-How , what and where would we look for life in a modern Viking mission? Biological and technological advances made after Viking suggest that we would use strategies other than Viking's to look for life.

-We will be better prepared to choose sites of biological interest as a result of the current set of ongoing and planned Mars missions

We can expand our search space on the surface by going back in time, at time when eater flowed across the surface. Looking for evidence of life, past or present, employs similar search strategies. Look for water. This is desired, not only because water is the quintessential ingredient for life, but also plays an important role in fossilization processes - our hope for preserved evidence of past life.

- We would not confine our sampling to the surface but would look deep under the surface as we know that terrestrial organism can exist many hundreds of meters below the earth's surface, independent of the surface - surviving on just rocks and water.

- We would not base our strategy on the consequences of life's presence (e.g. , chemical reactions or end products) but on what we believe to be the fundamental characteristics of life:

    -- self replication

    - heritable changes

    - selective barrier to the environment

- The Viking technology to look for life was based upon putting on Mars standard research tools, reduced in size, for studying a few specific aspects of biological chemistry

- I envision the new strategy to be based upon nanotechnological approaches working at the level of a few molecules or cellular units and capable of carrying out a large number of measurements - in essence a laboratory on a chip.:

-- It doesn't need to be Mars. Other planets and their moons might contain environments conducive to life, e.g., Europa

3. Life in the Cosmos: The Path Before Us

Missions of Exploration in the Solar System:

-Currently a number of unmanned missions to Mars are under way and under study. These missions, including robotic and sample return missions, will lay the groundwork for manned missions of exploration. These missions will be driven by science and the science that will drive them will be evolutionary biology.

-Evolutionary theory has identified a number of critical stages in the history of life on Earth. These stages mark major biological transitions: e.g. evolution from non-oxygen utilization to oxygen utilization, from asexual to sexual reproduction, from aquatic to terrestrial habitats, and from terrestrial to atmospheric . Evidence of these steps are all retrospective, i.e. fossil records, embryology, and biochemical patterns. What if we had had laboratories positioned to observe life during these critical transition? Imagine the observations that scientists might have made if they had had available fully equipped research laboratories at the time and place of one of these critical transitions and been able to collect relevant data. We hope to provide just such laboratories for what may be the next critical evolutionary transition: life leaving Earth.

-We stand at an important cusp in the history of life's history on Earth. For the first time in the Earth's history, humans can leave the planet . We are about to leave the surface of the Earth to explore and, possibly, to settle the Cosmos. This is a profoundly important biological event fully equal to the transition of life from water to land and from land to air. A critical feature of future missions of exploration will be research laboratories outfitted with a suite of research tools for studying biology, including cell and molecular biology, in these new planetary environments. This will provide the opportunity not only to investigate past or present life on the planet, but to study such questions as the effect of such alien environments, such as a gravity other than Earth's, on biological development and evolution.

Getting Ground Truth

Well, so what? What does investigating the life zone of this solar system do for us in our search for other solar systems?

It's our ground truth. We'll apply what we learn about the life zone in our solar system to our studies of worlds around other stars.

We've already found a number of Jupiter-sized bodies orbiting distant stars. Eight unusual palnetary systems. We will certainly detect more and smaller bodies that could include moons of those Jupiter-size planets, maybe even moons like Europa and Titan.

Only through understanding the conditions under which life can or did develop here, can we guess whether these new bodies are hospitable to life forms that we observed in our own solar system. We have no references for life forms we have observed, so we'll have to really be open and scientifically imaginative.

One question is not whether there are planets around other stars, but whether there are Earth-like planets (little blue / green balls) orbiting other stars or other planets, different from Earth, capable of supporting life as we know it.

Perhaps we'll find a blue/purple Earth-sized planet. Maybe instead of chlorophyll, we'll find rhodopsin in the photosynthetic reaction, but life could still be the same.

<u>How Can We Tell If There's Life on a Planet?</u>

When looking out at other star systems, how could we tell if life exists? What are the potential atmospheric signatures for life?

For the last 2 billion years, Earth's atmosphere has had a distinctive ozone signature -- a sure indicator of oxygenic photosynthesis. Chemical disequilibria is maintained by biology. For example, methane or nitrous oxide in the presence of oxygen were seen by as signs of life on the Earth as the Galileo spacecraft flew by.

Organic sulfur rich compounds could be indicative of life in a reducing atmosphere, like our Earth during its first 1.5 billion years. Certain complex chemicals that are by-products or waste products of life or a predominance of an optically active pigment, like chlorophyl or rhodopsin, could be indicators.

These are our guiding principles:

-NASA will be driven by science -- will seek to thoroughly integrate its programs into the broader scientific endeavor. We will support the broad, far ranging research that is required to attach these questions.

- Biology and information systems will be among the driving forces for science and technology in the next 25 years

-NASA's research must be multidisciplinary. We must bring together cell and evolutionary biologists, geneticists paleontologists physicists, chemists, engineers, information scientists l. We will engage other agencies and nations to leverage on their expertise and capabilities, We will work with the NSF, the NIH and the academy and the professional societies. will emulate the lesson from biology: That the most dynamic changes occurs at the interface between ecosystems-where the ocean meets the land.

- We will provide new vistas and dreams for young people. We will look out as far as the aided eye can see and as far as the translated hand hand can touch and explore the laws of nature to understand our origins and enrich the lives of our children.

- we will develop New technologies based upon biological processes and systems
    - A "chemical nose" to detect hundreds of volatile organic substances
    - Accelerometers based upon the inner ear
    - DNA-based biomedical diagnostic sensors
    - Self diagnosing and repairing mechanical systems
    - Biological production of non-biological materials
    - robotic explorers equiped with tri-corders

- intellectual, scientific and technological pursuits; including evolutionary biology, always will come back to benefit humans.

Looking down from the height of space and out at the heavens, can we connect the relationships between oceans, atmosphere, and land. What is the role of life in these relationships. How has evolution functioned to stabilize them? -- and, can we ensure a sustainable planet?